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A MODEL DROP TECHNIQUE FOR FREE-FLIGHT MEASUREMENTS IN HYPERSONIC WIND TUNNELS USING TELEMETRY

L. K. Ward and R. H. Choate

ARO, Inc.

May 1966

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NOTICES

A MODEL DROP TECHNIQUE FOR FREE-FLIGHT MEASUREMENTS IN HYPERSONIC WIND TUNNELS USING TELEMETRY

L. K. Ward and R. H. Choate
ARO, Inc.

FOREWORD

The work reported herein was done at the request of Headquarters, Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 62405334, Project 8952, Task 895201.

The results of research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract AF40 (600)-1200. The work was done under ARO Project Numbers VT3444 and VG3417, and the manuscript was submitted for publication on March 22, 1966.

This technical report has been reviewed and is approved.

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ABSTRACT

A technique to provide model pressure and heating rate measurements free from support interference has been developed for the continuous flow, hypersonic wind tunnels (Mach numbers 6, 8, and 10) in the von Kármán Gas Dynamics Facility. Data may be obtained from models up to 12 in. in length and 4.5 in. in diameter using onboard telemetry. A description of the test equipment and instrumentation is presented, in addition to base pressure measurements obtained on a 10-deg half-angle cone and base heating measurements obtained on a 10-deg half-angle, rounded base cone at Mach 10.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

C	Capacitance, farads
f_o	Telemeter center frequency, cps
L	Inductance, henrys
M_∞	Free-stream Mach number
p_b	Model base pressure, psia
p_∞	Free-stream pressure, psia
Δp	Differential pressure, psid
$\dot{q}$	Heat-transfer rate, Btu/ft^2-sec
R	Resistance, ohms
Re_ℓ	Free-stream Reynolds number, based on model length
r_b	Model base radius, in.
r_n	Model nose radius, in.
T	Temperature, °K
t	Time, sec
α	Angle of attack, deg
θ_c	Cone half-angle, deg

SECTION I
INTRODUCTION

A program has been underway at the von Kármán Gas Dynamics Facility (VKF) to develop model free-flight testing capabilities in wind tunnels operating at Mach numbers ranging from 1.5 through 10. A pneumatically operated model launcher was developed to launch models in the VKF 40-in. supersonic tunnel, the 50-in. Mach 8 tunnel, and the 50-in. Mach 10 tunnel (Gas Dynamic Wind Tunnels, Supersonic (A) and Hypersonic (B) and (C)). The objectives were to obtain model drag, damping, pitching-moment rate, and base pressure data. During the course of this development, a different model launch technique was conceived for obtaining model base pressure and base heating rate measurements in Tunnels B and C. This technique allows the test model to fall through the tunnel flow and to be recovered, undamaged, without interrupting the tunnel operation. Model base pressure and base heating measurements are obtained using single-channel onboard telemetry systems. The "drop" technique has the following advantages over gun launching models in wind tunnels for obtaining measurements via telemetry systems:

1. One model may be tested repeatedly.
2. Larger models may be tested.
3. Check calibrations of the telemetry system may always be made after the data have been obtained.

SECTION II
APPARATUS

2.1 WIND TUNNELS

The model drop technique was developed specifically for use in Tunnels B and C which are continuous, closed-circuit, variable density wind tunnels equipped with contoured, axisymmetric nozzles. Tunnel C operates at a nominal Mach number of 10, at stagnation pressures ranging from 200 to 2000 psia, and at stagnation temperatures up to 1450°F. Tunnel B operates at a nominal Mach number of 6 at stagnation temperatures up to 390°F for stagnation pressures ranging from 20 to 300 psia and at Mach number 8 at stagnation temperatures up to 890°F for stagnation pressures ranging from 50 to 900 psia. Both tunnels have identical test sections (Tunnel C is shown in Fig. 1)

and model injection systems. These systems allow the test article to be injected into the tunnel test section from the test section tank. In addition, the tank may be sealed from the test section and vented to atmosphere, thus allowing model work to be accomplished while the tunnel is running. This somewhat unique operation provided the foundation of the model drop technique currently in use.

Tests to evaluate the drop technique were conducted in Tunnel C.

2.2 MODEL DROP MECHANISM

Figure 2 shows a sketch of the drop mechanism installed on the top window flange of Tunnel C. The drop mechanism consists of the model release mechanism (partially omitted for clarity) and its housing, the sliding valve assembly, the water-cooled strut, which protrudes through the tunnel boundary layer, and the splitter plate. The model release mechanism is shown in Fig. 3 with a test model installed. The top of the model is supported by an adjustable epoxy resin saddle which is formed to the model upper contour. The releasing arm is spring-loaded and is held against the model by a solenoid-operated lever. The knife edge on the releasing arm may be adjusted for final model positioning. The insert shows the mechanism after model release.

2.3 MODELS

Sketches of the model configurations tested are shown in Fig. 4. The forward sections of the models were constructed of stainless steel to provide a high weight-to-drag ratio. The aft sections were constructed of Lexan® (a polycarbonate resin) to permit telemetry transmission through the model wall. A photograph of the pressure-telemetry model is shown in Fig. 5 along with a pressure-telemetry package attached to the model base plate.

2.4 INSTRUMENTATION

2.4.1 Telemetry Systems

The telemeters located aboard the free-flight models were transistorized oscillators operating at center frequencies in the 165- to 180-mc range. These oscillators were directly frequency modulated by either variable capacitance (pressure) or variable resistance (heat-transfer) transducers. The telemeters were rigidly encapsulated in epoxy resin to provide both thermal and shock insulation.

Both the telemeter operating frequency and calibration sensitivity are affected by temperature changes (Ref. 1); however, no temperature effects were noted during the present tests. This may be attributed to the short time duration (150 msec) that the model is exposed to the tunnel flow and the low thermal conductivity of the materials surrounding the telemeter.

2.4.1.1 Pressure Telemeters

Two types of oscillator circuits (Fig. 6) were used for single-channel pressure telemeter construction. Both types were supplied with constant emitter current bias from the tapped power supply, eliminating the bias voltage divider resistors previously used (Ref. 2). This resulted in circuits relatively immune to variations in transistor characteristics. Current drain for both the Colpitts-type and Clapp-type telemeters was nominally 1 ma from a 5.4-v source. The Clapp-type telemeter developed during these tests is preferred over the Colpitts-type because the Clapp circuit is relatively unaffected by nearby objects. The Colpitts-type telemeter required shielding (Ref. 1) to prevent extraneous frequency shifts caused by proximity effects, whereas the Clapp-type did not. The components used in fabrication of the telemeters, all commercially available except for the transducers, are described in Ref. 2.

Variable capacitance, differential-pressure transducers (Fig. 7) provided center frequency deviations of the pressure telemeters as functions of applied pressure. Quiescent transducer capacitance was nominally 10 pf, with changes of about 0.6 pf resulting from the application of 0.1 psid. A pressure lag circuit was employed on the reference side of the transducer to ensure that the reference pressure remained essentially constant during the period of time that the model was exposed to the tunnel flow. Further transducer details and operating characteristics are given in Ref. 1.

2.4.1.2 Heat-Transfer Telemeter

A circuit diagram of the heat-transfer telemeter used in these tests is shown in Fig. 8. This single-channel, heat-transfer telemeter was used to obtain all the heat-transfer data in these tests. Circuit sensitivity to the various heat-transfer rates was adjusted using resistor networks in the transducer leads. A differential-amplifier driver stage between the transducer and the oscillator replaced the single-ended driver previously used. This change provided more telemeter output (frequency deviation per unit transducer resistance change) for measuring heat-transfer rates ($\dot{q}$) below 0.5 Btu/ft^2-sec.

The variable resistance transducers used for heat-transfer measurements were of the type shown in Fig. 9. The calorimeter-type transducers (0.003-in. disc thicknesses) had deposited thin-film platinum resistors to sense the temperature rise of the calorimeter disc. An exception was made for a transducer located on the base at the model's centerline. This unit (0.006-in. disc thickness) employed a Temp Sensor® (variable resistance semiconductor) as the sensing element. A detailed description of this heat-transfer transducer is presented in Ref. 3. All the transducers used in these tests were sprayed in one operation with a high absorptivity (~0.98) coating to ensure uniform response to the radiation source used for calibration.

2.4.2 Receiving and Recording Systems

A stub antenna, positioned vertically on the tunnel window, provided satisfactory free-flight reception. A preamplifier between the antenna and receiver was sometimes used to compensate for the reduced output of the shielded, Colpitts-type telemeters. A commercially available FM receiver with a nominal discriminator bandwidth of ±600 kc was used throughout the tests. The receiver was modified to provide a d-c output voltage proportional to frequency deviation, which was recorded on an oscillograph through a d-c amplifier. Another modification provided a separate output to the oscillograph whereby galvanometer deflection was a function of the strength of the received signal, giving a continuous record of signal strength throughout the free-flight period. This allowed erroneous data resulting from insufficient signal strength to be recognized. A direct-writing oscillograph was used so that data could be observed immediately following each run.

SECTION III
PROCEDURE

3.1 TELEMETER CALIBRATION

3.1.1 Pressure Telemeters

Pressure telemeters were isolated in a bell jar at some arbitrary reference pressure between 0.002 and 4.0 psia during calibration. A three-way solenoid valve allowed the telemeter pressure measurement port to be alternately connected either to the reference pressure bell jar containing the telemeter ($\Delta p = 0$), or to an adjoining bell jar at a different absolute pressure, thus establishing a differential pressure across the pressure telemeter. Differential pressure between bell jars

was measured with a precision micromanometer having a nominal resolution of ±0.000068 psid. Reference pressure was arbitrarily varied between different calibration runs to verify that no calibration sensitivity changes arose from changes in ambient pressure level.

The calibration repeatability of the Clapp-type telemeter, both before and after many model drops, is shown in Fig. 10. Corresponding curves for the Colpitts-type telemeter, as well as a further description of the calibration apparatus, are contained in Ref. 1. As seen in Fig. 10, calibration repeatabilities generally within ±2 percent of reading were obtained.

3.1.2 Heat-Transfer Telemeter

A high-intensity, quartz-iodine lamp ($T > 1000°K$) was used as a radiation-type, heat flux source. This source allowed telemeter calibrations to be performed in the range of interest (near 1 Btu/ft^2-sec).

A calorimeter-type thermocouple heat-transfer transducer (Ref. 4), sprayed with a black, high-absorptivity coating at the same time as the telemeter transducers, was used as a calibration transfer standard. This transducer was calibrated using a convective heat flux source whose output was measured with a slug calorimeter, used as a primary standard. Because of the approximately linear relationship existing between calorimeter disc temperature, transducer output, frequency deviation, and galvanometer deflection, the slope of the recorded data was proportional to heat-transfer rate.

The radiation-type heat flux source output was measured using the calibrated transfer standard. The telemeter transducers were substituted, one at a time, for the standard transducer and exposed to the radiation-type source. Exposure time was the same in all cases, approximately 0.1 sec. Using this method, telemeter calibration constants, assumed independent of heat-transfer rate in this range (Refs. 3 and 4), were obtained for each telemetry channel. The heat-transfer telemeter calibration constants, both before and after tunnel testing, are shown in Fig. 11. The large calibration constant change noted for telemeter 4 (approximately 18 percent) presumably resulted from the fact that some of the high absorptivity coating on the transducer was lost, either during or after the tunnel tests. The remaining four channels show calibration repeatabilities within 8.5 percent.

3.2 TUNNEL TESTING

3.2.1 Preliminary Tests

Several model drop tests were made in Tunnel C with no tunnel flow, primarily to determine the most satisfactory location for the telemetry antennas. Two antennas were found necessary, one on the tunnel window for free-flight reception and one inside the removable housing (Fig. 2) for pre-test receiver tuning. Paralleling these antennas resulted in marginal reception from both systems. A timing circuit, actuated by the model releasing arm, was devised to switch from the housing antenna as the model passed through the water-cooled strut (Fig. 2). This arrangement proved satisfactory, as shown in Fig. 12. As seen in this figure, galvanometers were used as event markers to indicate model release and antenna switching. Although signal dropout occurred as the model passed through the water-cooled strut (at which time the antennas were switched), the reception obtained as the model fell through the tunnel test section (t = 450 to 600 msec) was excellent. The signal strength variations noted during free-flight through the test section are seen to have no effect upon the telemetered pressure trace. Photographs of the model during these wind-off drop tests showed no model misalignment with reference to the tunnel centerline, indicating positive operation of the release mechanism.

3.2.2 Tunnel Tests

During the free-flight tests conducted in Tunnel C, the procedure followed was to install the model in the release mechanism (Fig. 2) and secure the removable housing in place. The housing chamber was then vented to the tunnel and the sliding valve opened along with the tunnel doors. The oscillograph was started and the model released to drop through the test section flow and into the model catcher located in the test section tank (Fig. 2). The model was then recovered and repositioned in the release mechanism for the next drop.

During the base pressure tests, the absolute average pressure inside the mechanism housing (telemetry transducer reference pressure) was recorded immediately prior to model release. The absolute base pressure of the model was the algebraic sum of this reference pressure and the telemetered differential pressure.

Pressure changes in the housing or in the test section tank were made slowly in order not to overpressure the telemetry transducer and possibly affect its calibration characteristics. Even with these delays,

4 to 5 model drops could be made each hour. The base heating tests could be run more rapidly because one run required only about 5 min.

SECTION IV
RESULTS AND DISCUSSION

4.1 BASE PRESSURE TESTS

The results of the free-flight base pressure measurements are shown in Fig. 13 as the base pressure ratio (p_b/p_∞) variation with length Reynolds number (Re_ℓ). The model boundary layer is known to be laminar (α = 0) throughout the Reynolds number range tested. The trend depicted by the data shows the expected decrease with increasing Reynolds number for conical bodies in this Reynolds number range. Also shown is a prediction of the base pressure ratio at α = 0 for turbulent flow from work by Cassanto (Ref. 5). Boundary-layer transition data on a 10-deg cone in Tunnel C (Ref. 6) indicate that the transition Reynolds number (transition at model base) is between 3.2×10^6 and 4.3×10^6. A comparison of the experimental data and the theory appears to be consistent with a typical base pressure variation with Reynolds number (Insert, Fig. 13).

During the tests it was noted that as Reynolds number was increased, a definite pattern formed in the time variation of Δp obtained from the telemeter. The Δp measured during the time the model was in the tunnel flow showed a somewhat sinusoidal time variation (Fig. 14). This variation was consistent for several drops at the same tunnel conditions. The frequency and amplitude of this variation increased with Reynolds number (Fig. 15) but was not noticed at Reynolds numbers below about 10^6. Model oscillations in the pitch plane were observed in movies taken during a number of the drops, and the model frequency was about one-half the frequency of the Δp variation. It is felt that the model oscillation was initiated by the unsymmetrical loading on the model as it entered the tunnel flow and that the time variation of Δp was caused by the model oscillation. The magnitude of the variation is within the repeatibility scatter of the data, and the data shown in Fig. 13 are the average values obtained during a drop. As may be seen in Fig. 13, absolute values of p_b in the range of 0.0045 psia were obtained with a repeatability within 0.001 psia ($Re_\ell = 0.5 \times 10^6$).

4.2 BASE HEATING TESTS

The initial base heating tests were made using a flat base cone model with the transducer located in the center of the base. Results

of these tests showed no discernible heating rates present at the maximum Reynolds number condition in Tunnel C. The test model was then modified to have a rounded base, with the transducers located on the conical surface, on the rounded shoulder, and at the base center. The locations of the transducers and the results of the tests are shown in Fig. 16. The cone surface measurements ($\dot{q}$) are in fair agreement with theory, and the heating rate decreases around the shoulder as would be expected. No explanation is given for the higher heating rate at the base center as compared to the point located about 0.15 in. from the base.

SECTION V
CONCLUDING REMARKS

A technique has been developed at VKF to obtain free-flight base pressure and base heating data in Tunnels B and C using onboard telemetry in relatively large test models. The models may be recovered and tested repeatedly without interrupting tunnel operation. Model base pressure and base heating results obtained during evaluation of the technique indicate that pressures on the order of 0.004 psia and heating rates on the order of 0.1 Btu/ft^2-sec were successfully measured.

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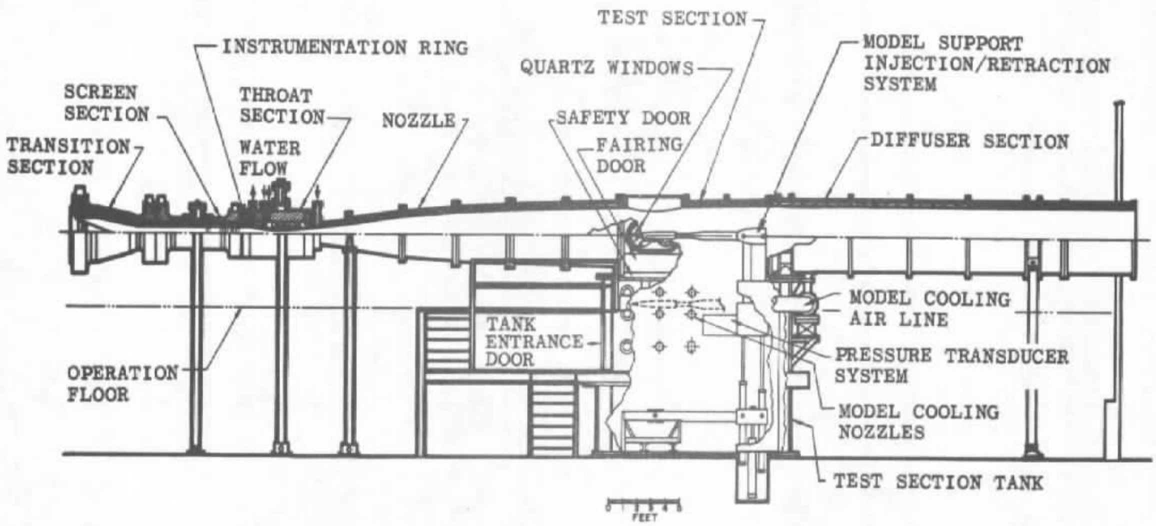
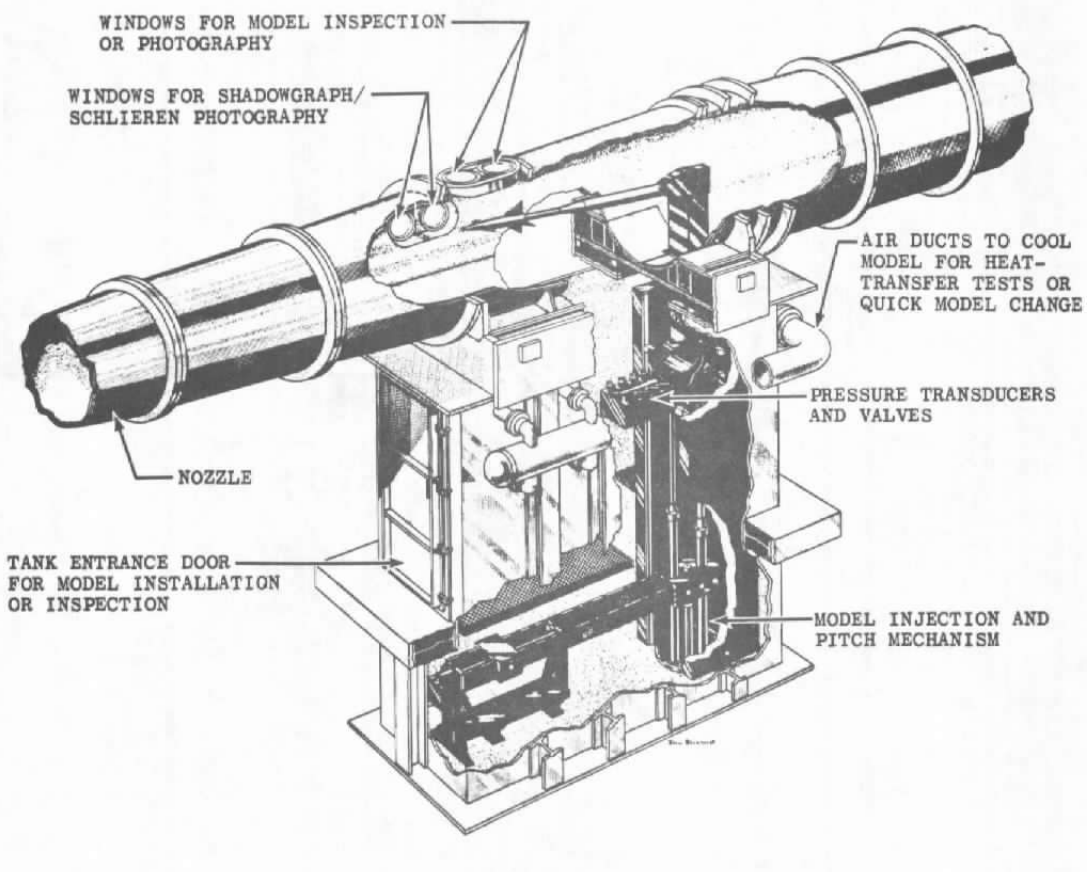


Tunnel Assembly



Tunnel Test Section

Fig. 1 Tunnel C

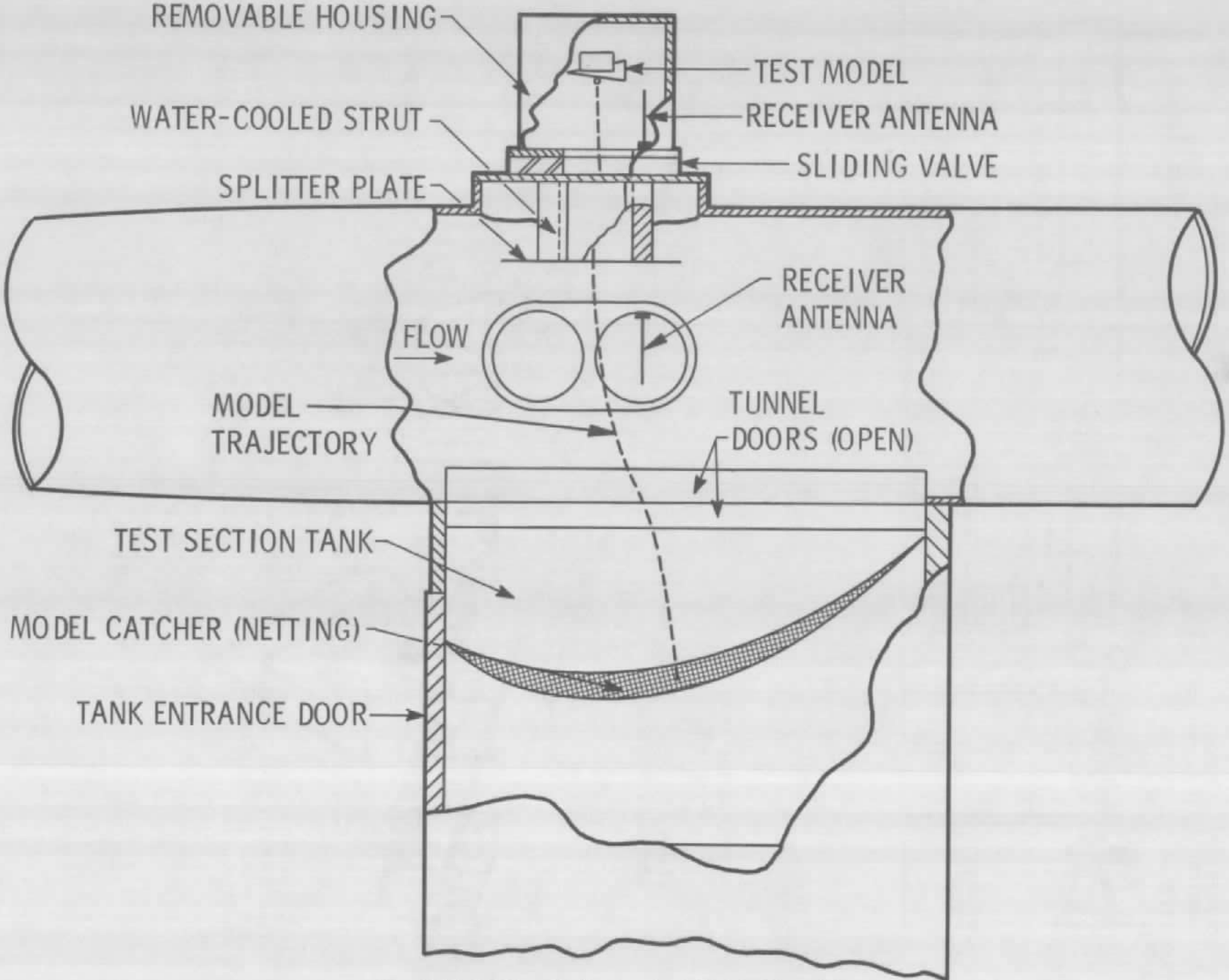


Fig. 2 Model Drop Mechanism Installed in Tunnel C

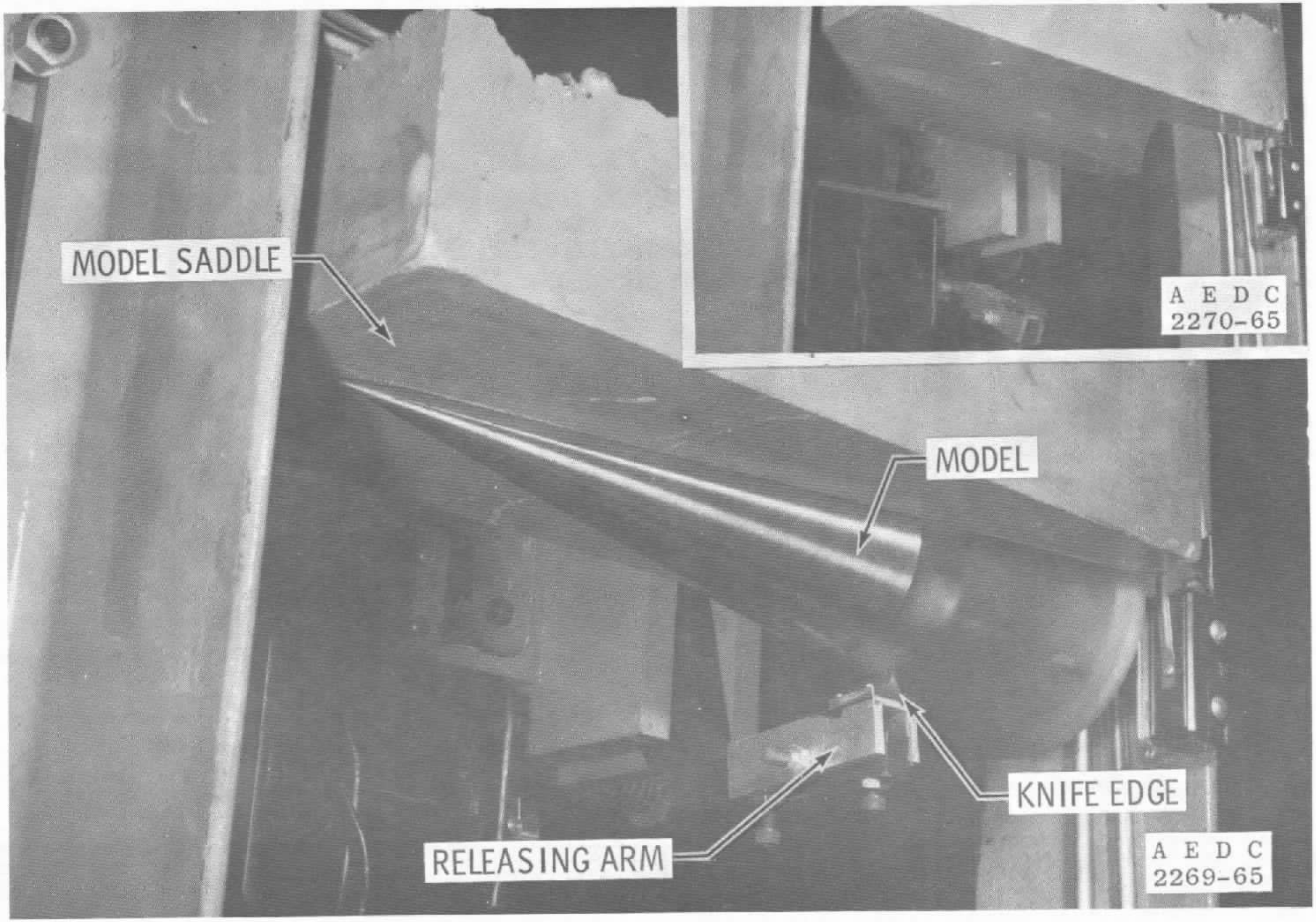
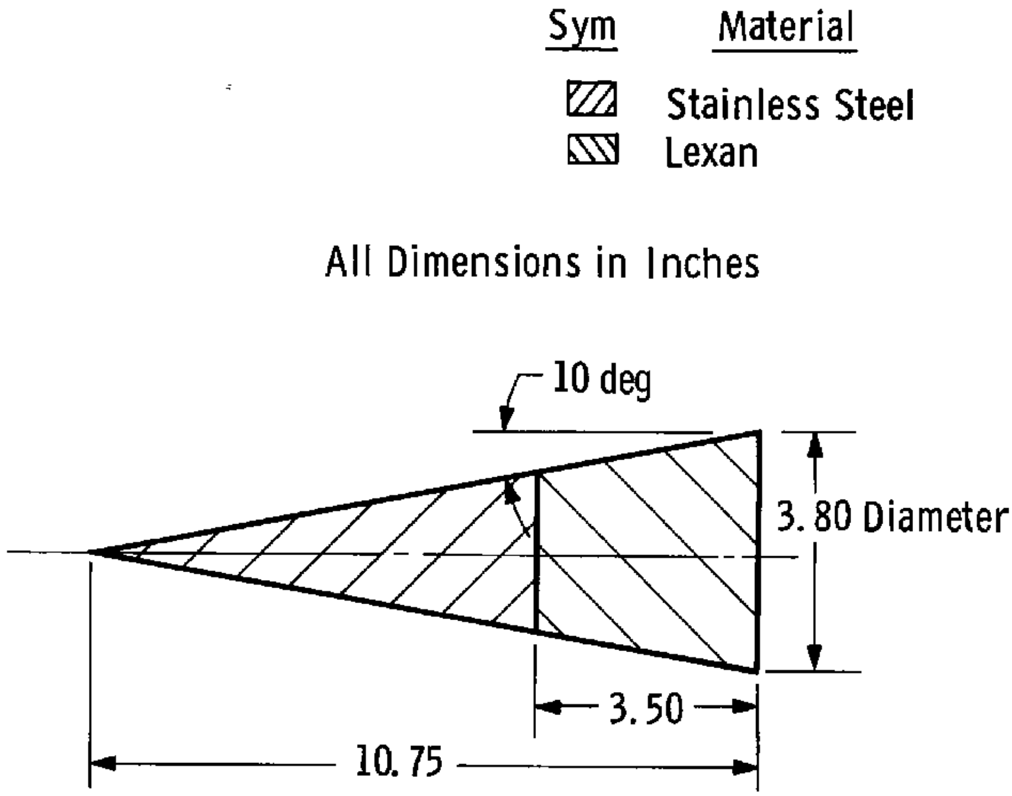
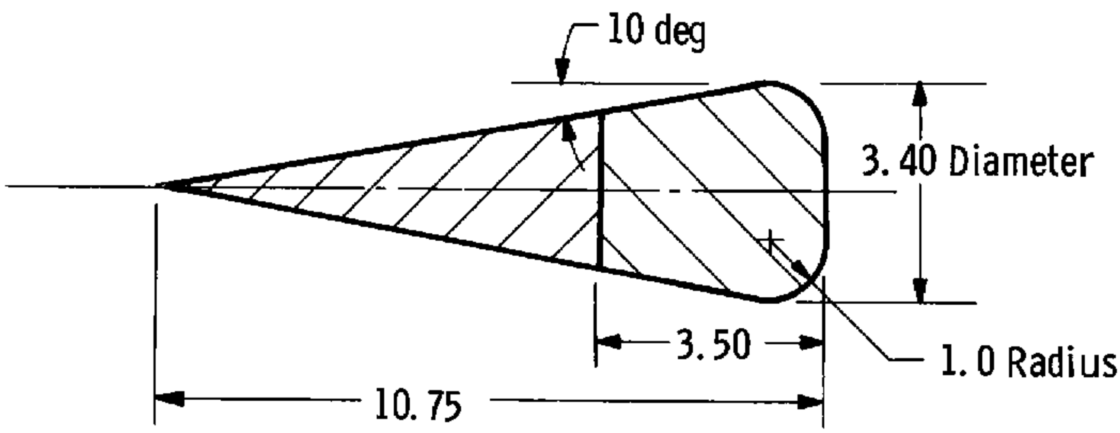


Fig. 3 Model Release Mechanism



a. Base Pressure Model



b. Heat-Transfer Model

Fig. 4 Sketches of the Test Models

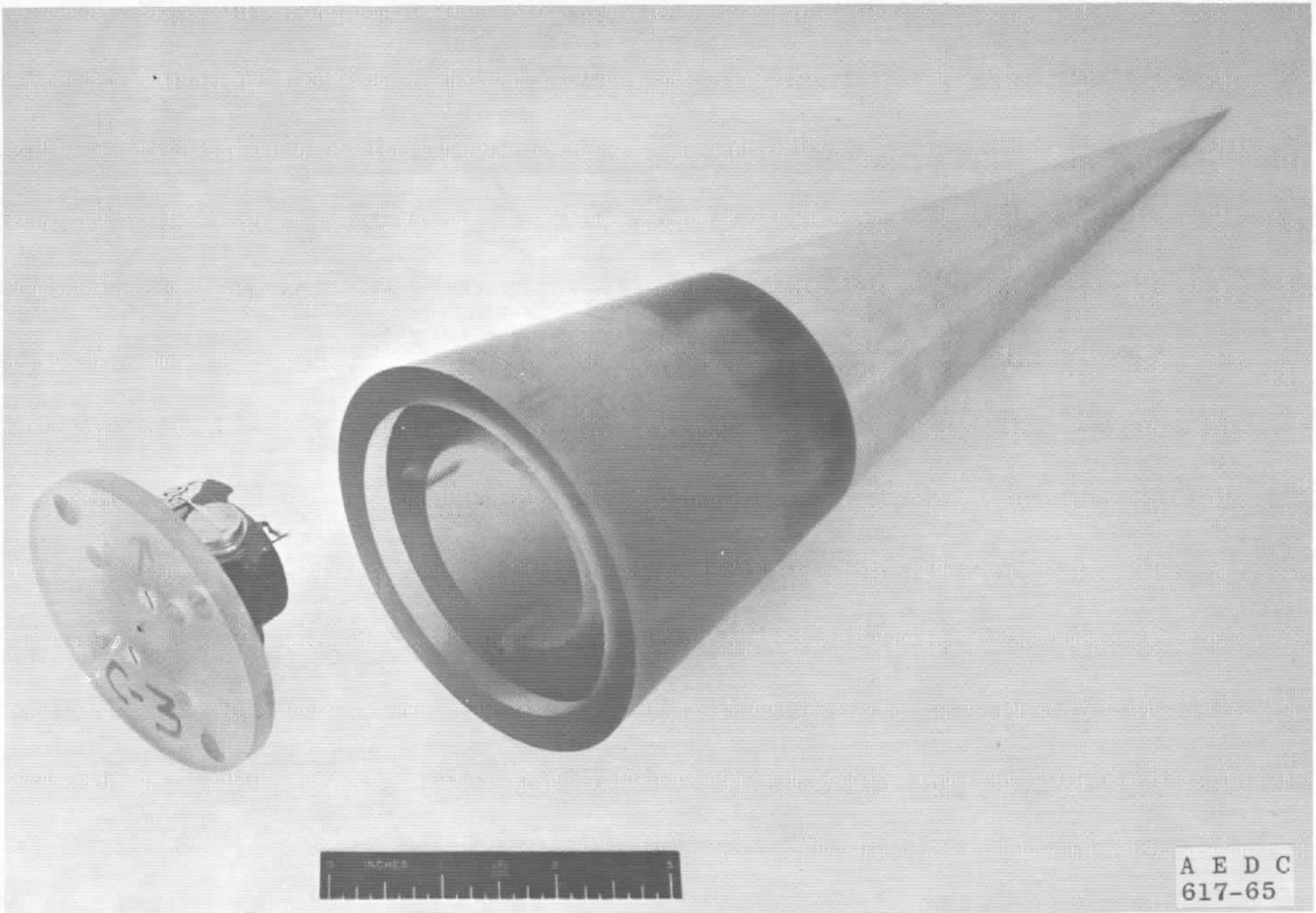
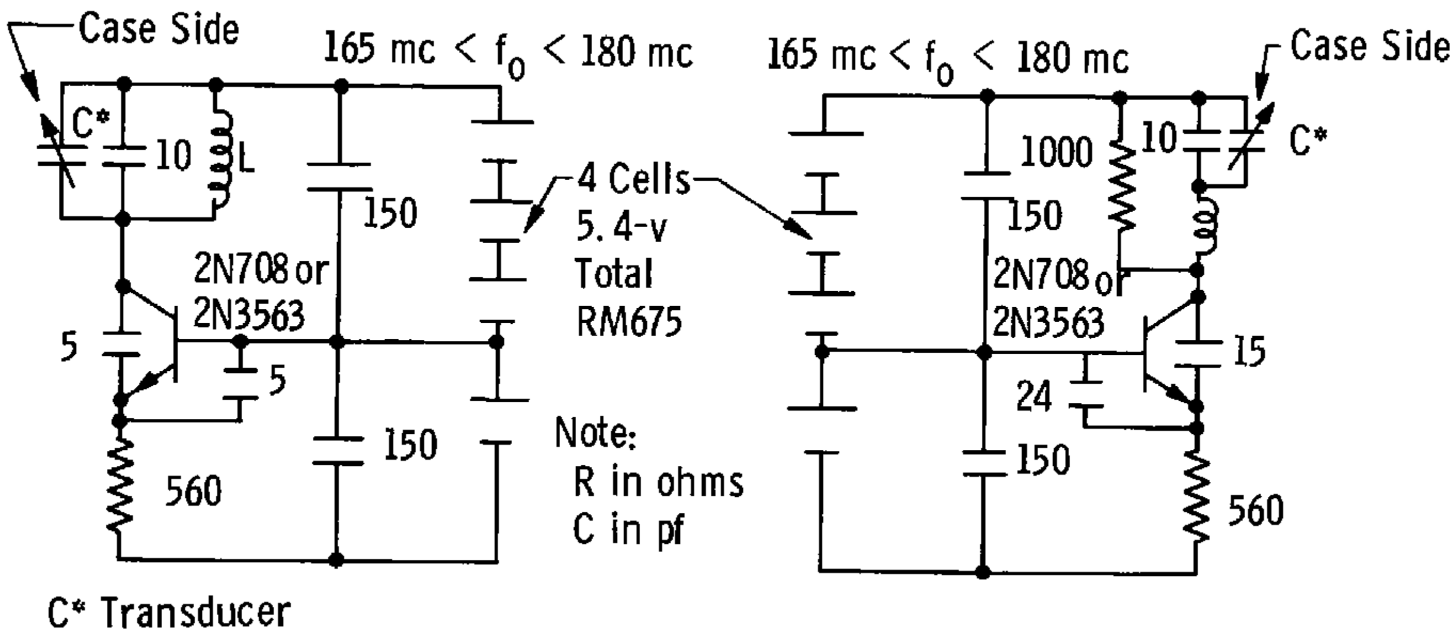


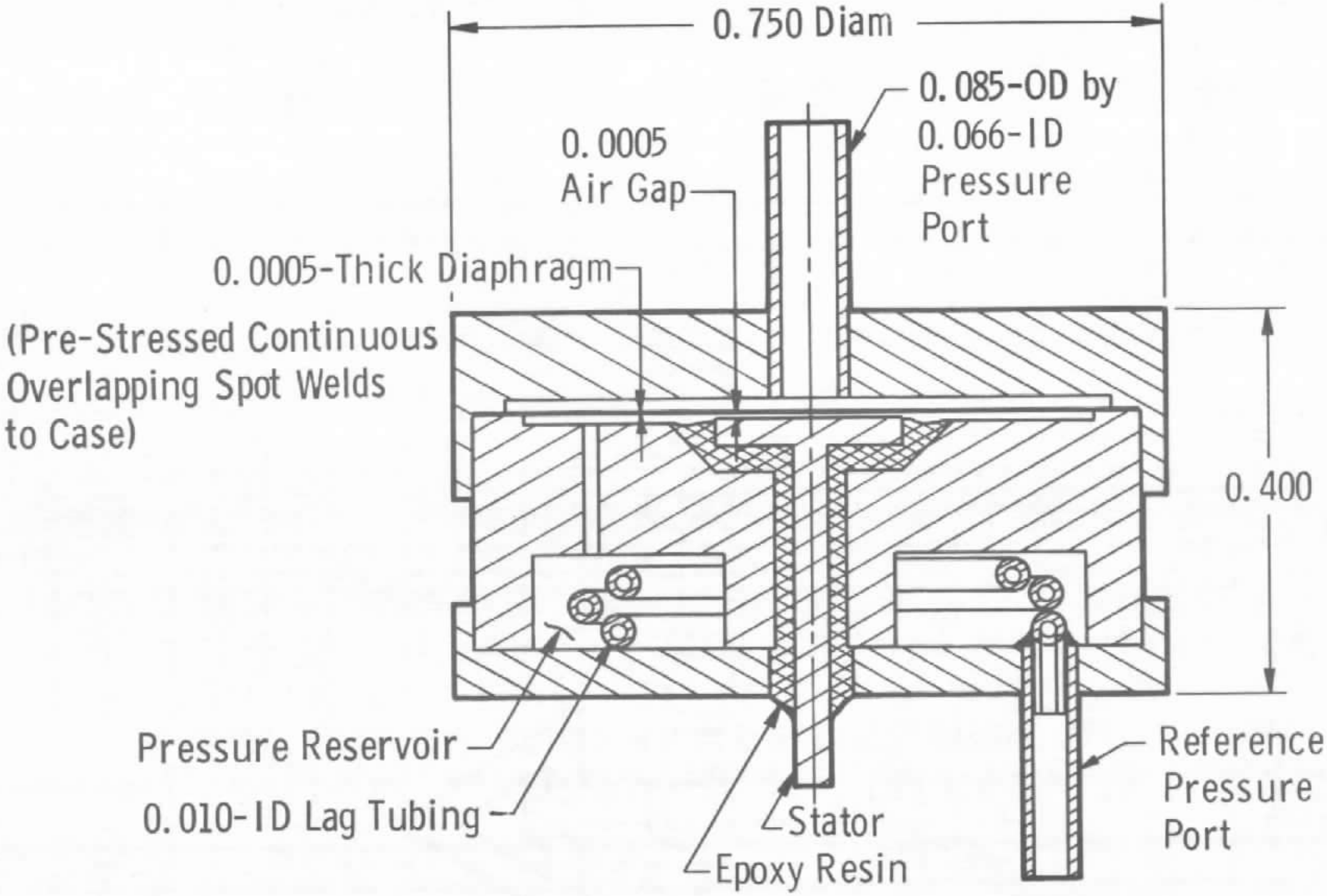
Fig. 5 Photograph of the Base Pressure Model



a. Colpitts-Type Oscillator

b. Clapp-Type Oscillator

Fig. 6 Pressure Telemeters



Transducer Material: 302 Stainless Steel

Dimensions are in inches.

Fig. 7 Pressure Transducer

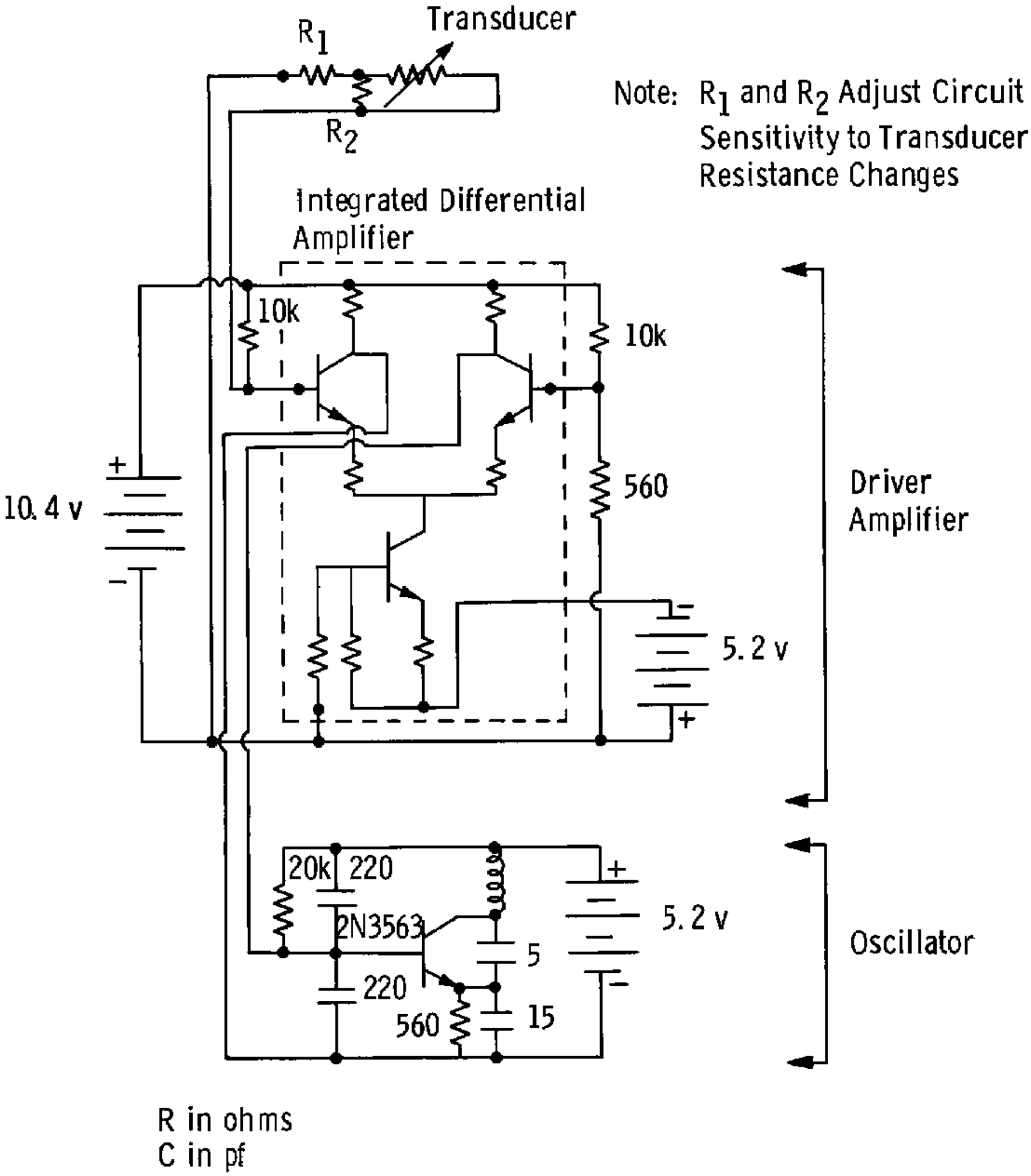


Fig. 8 Heat-Transfer Telemeter

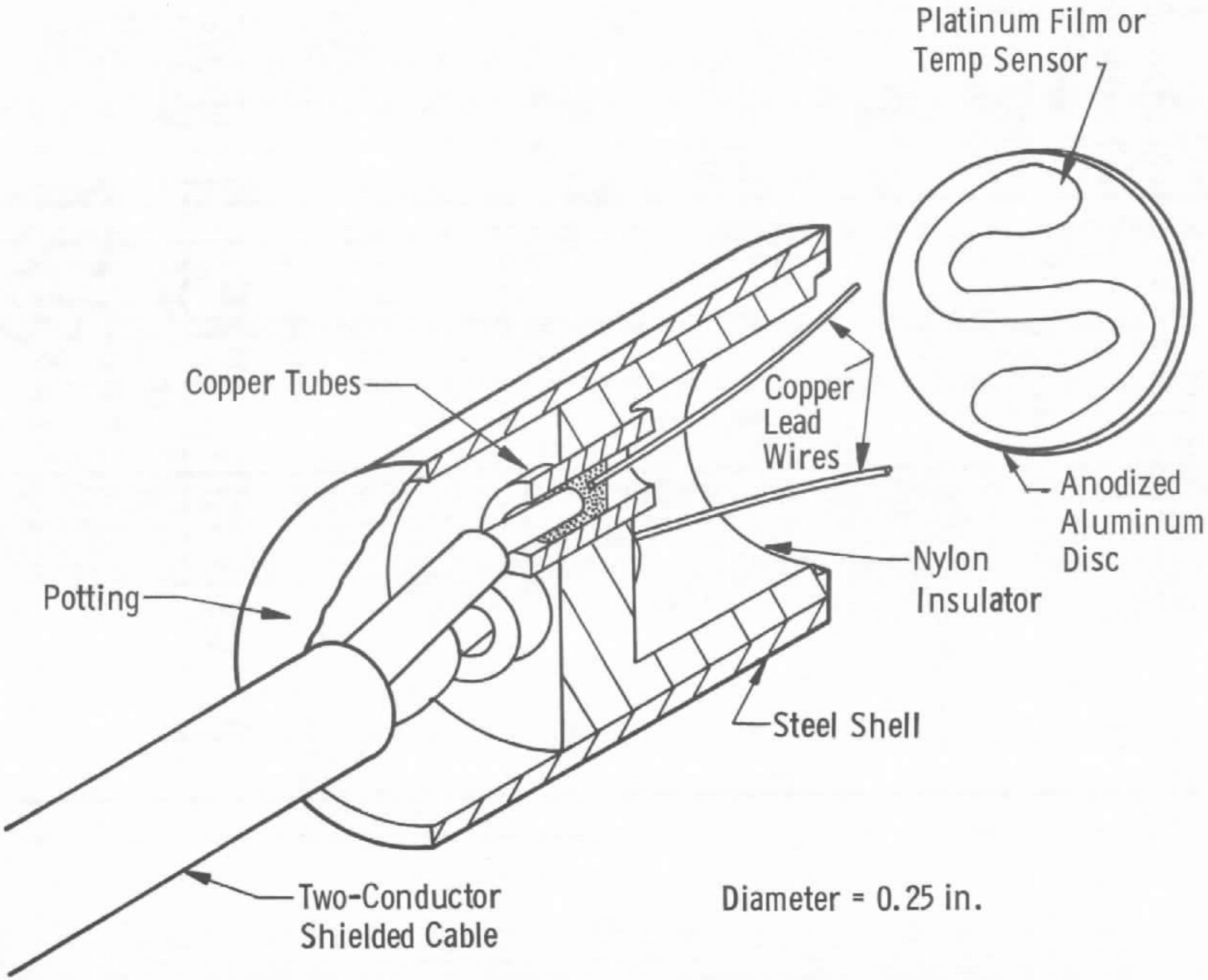


Fig. 9 Heat-Transfer Transducer

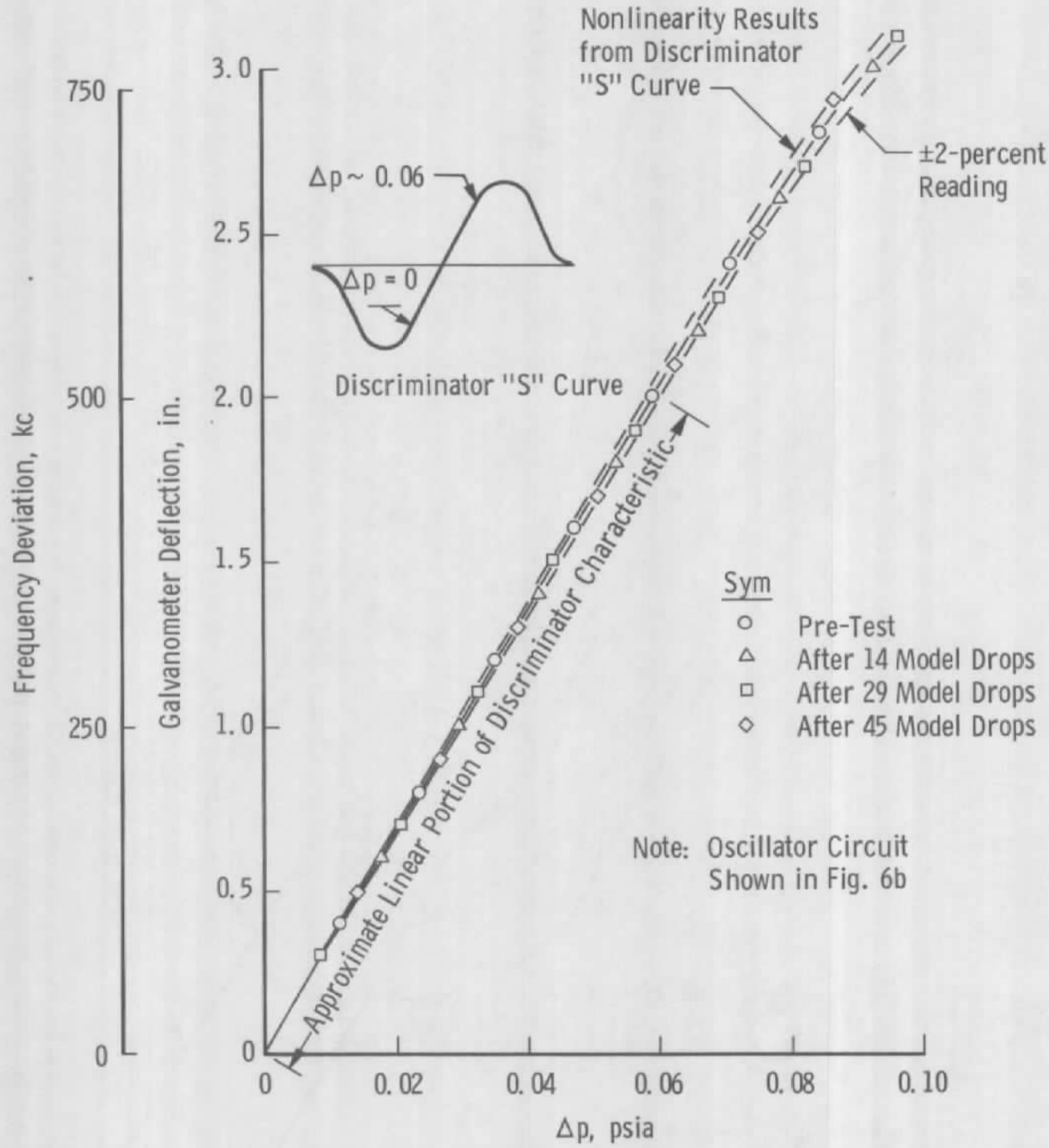


Fig. 10 Pressure Telemeter Calibration Repeatibility for a Clapp-Type Oscillator

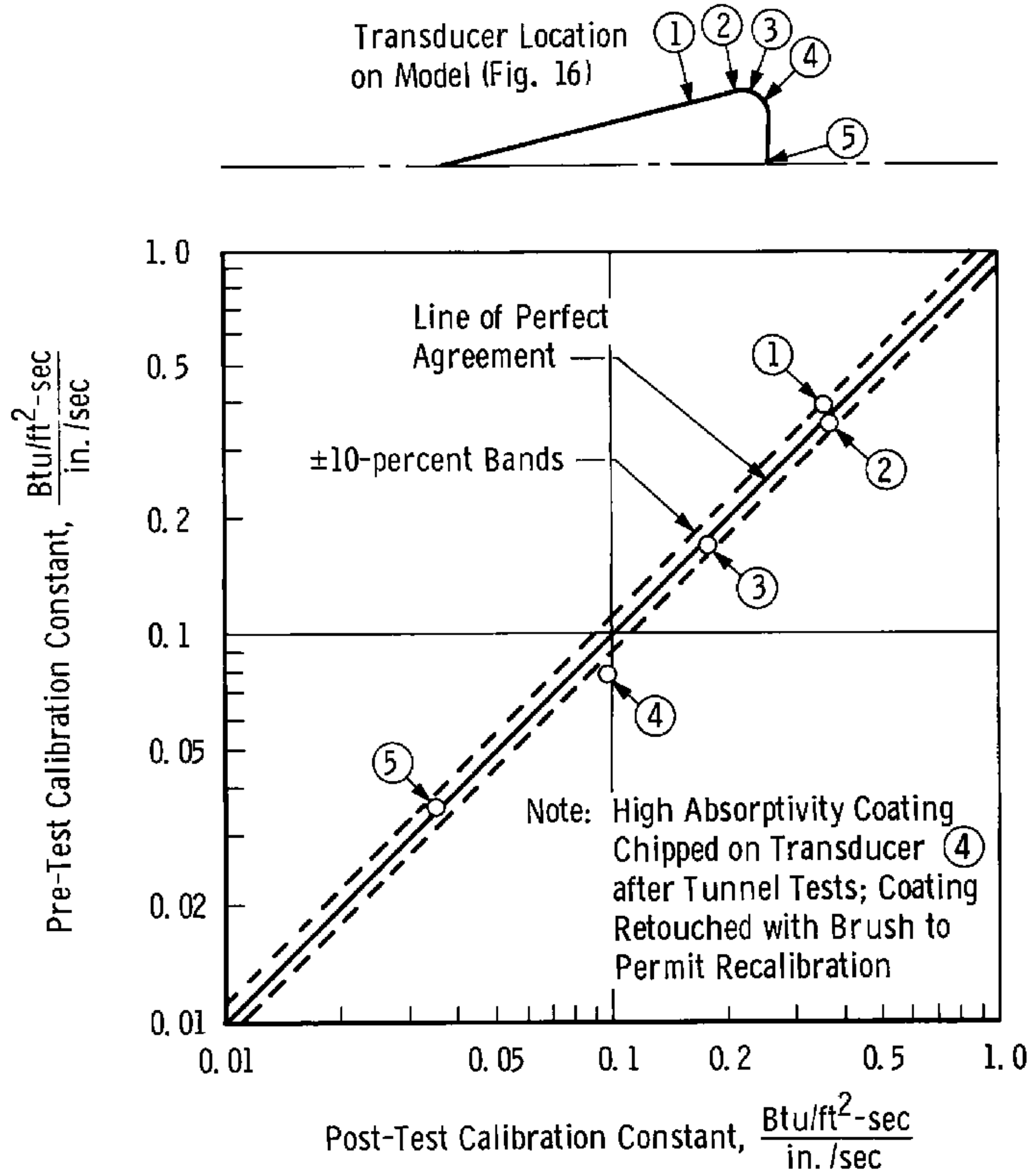


Fig. 11 Heat-Transfer Telemeter Calibration Repeatibility

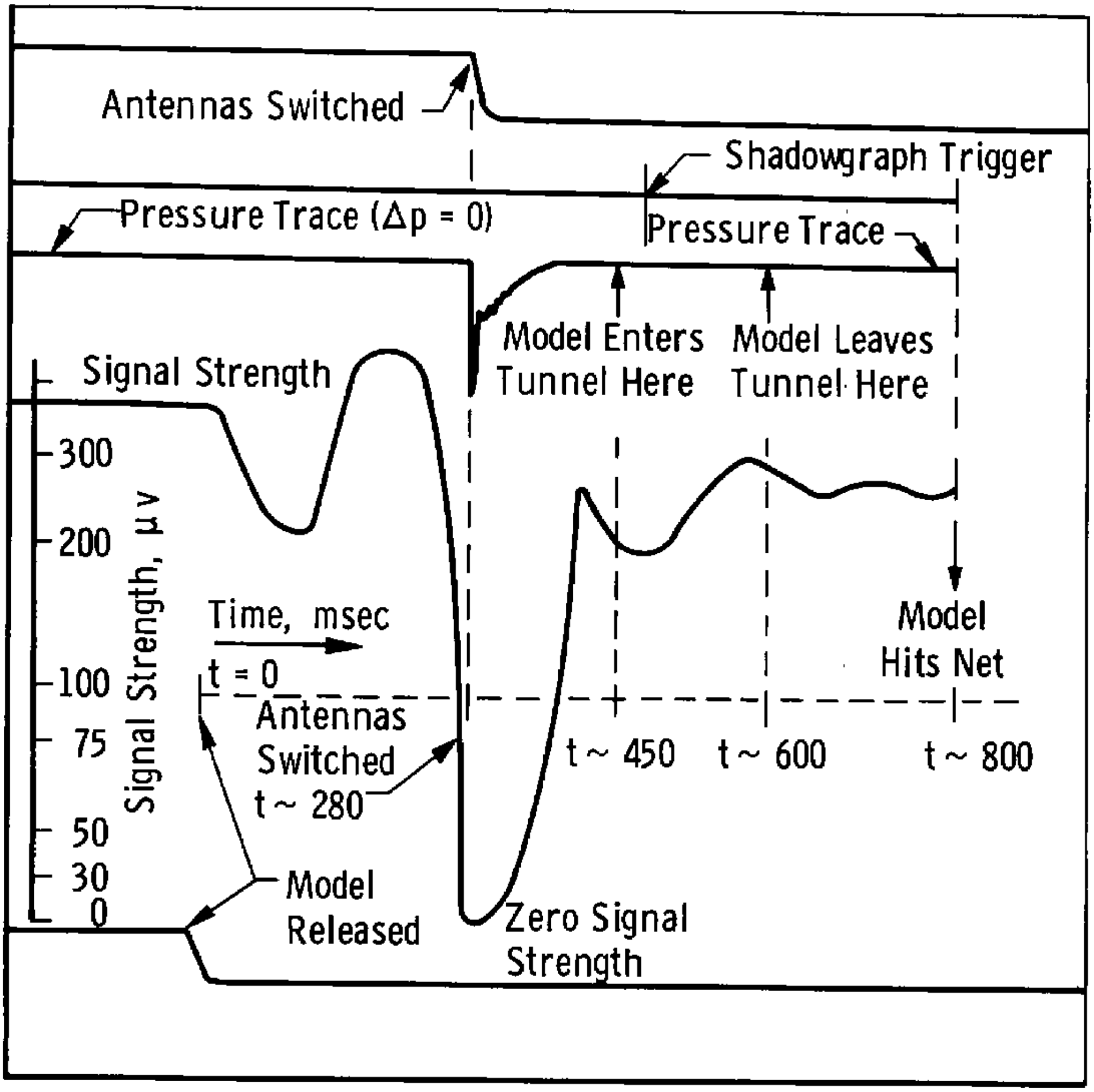


Fig. 12 Typical Oscillograph Trace Obtained in Tunnel C during Wind-Off Tests

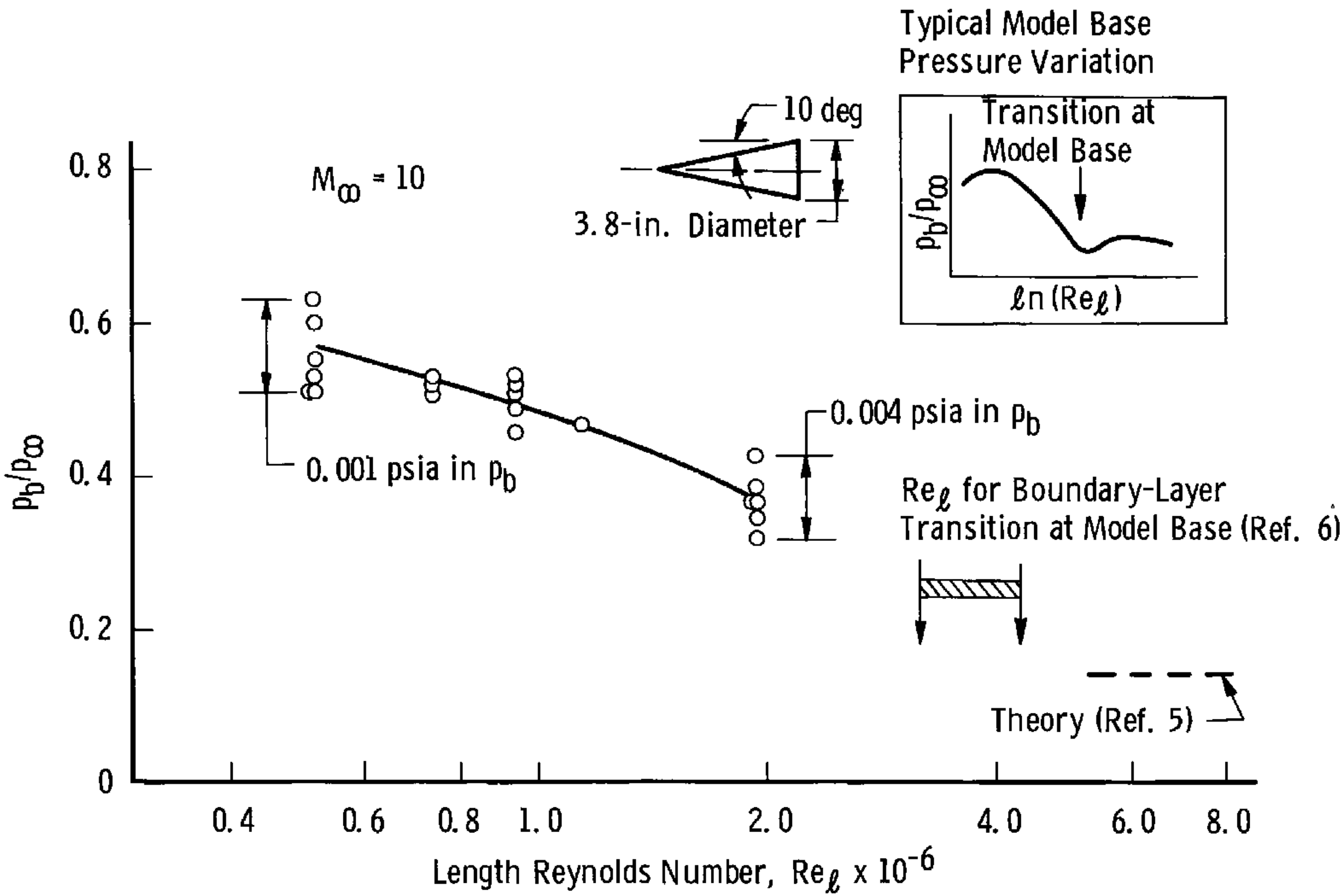


Fig. 13 Model Base Pressure Results

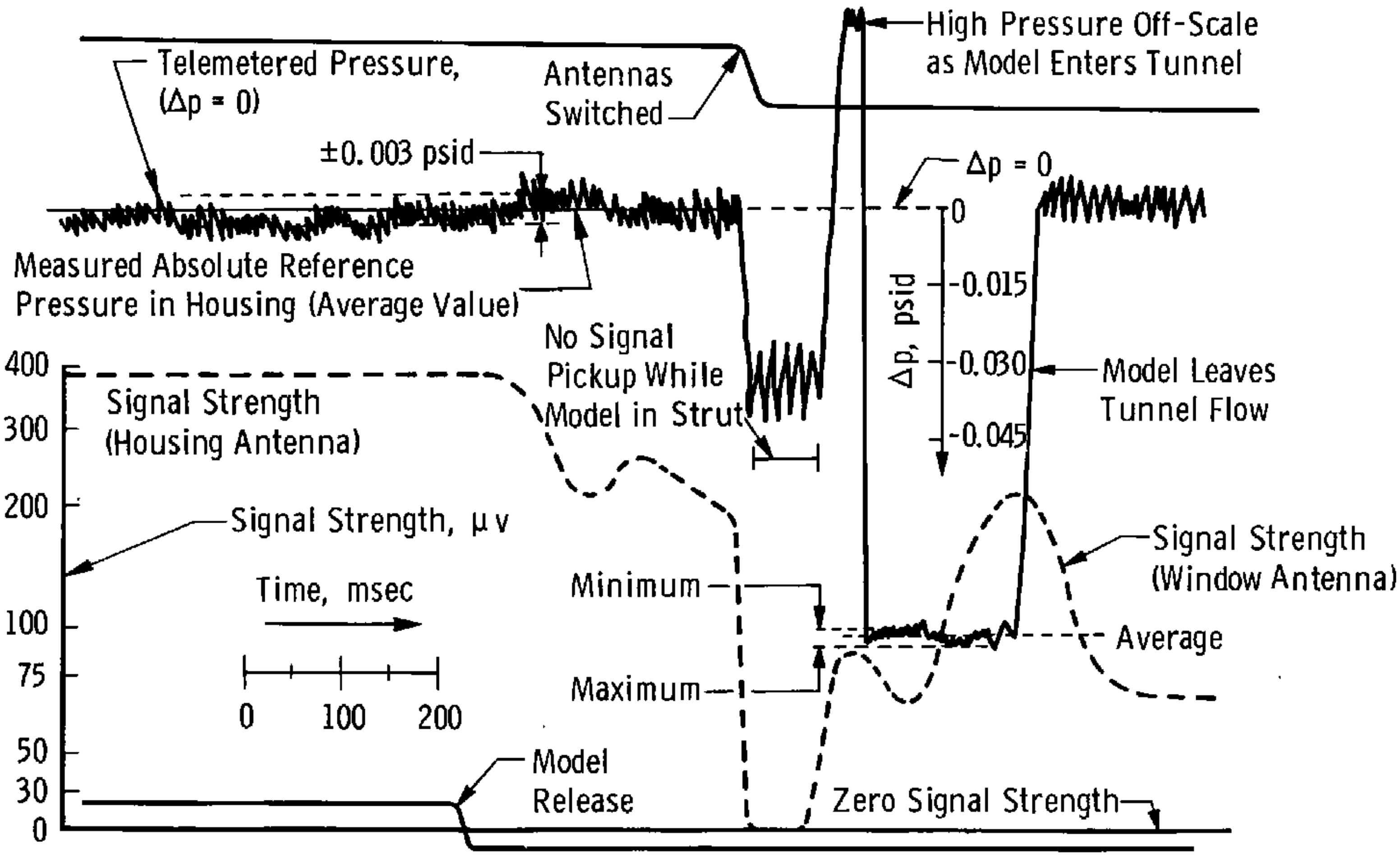
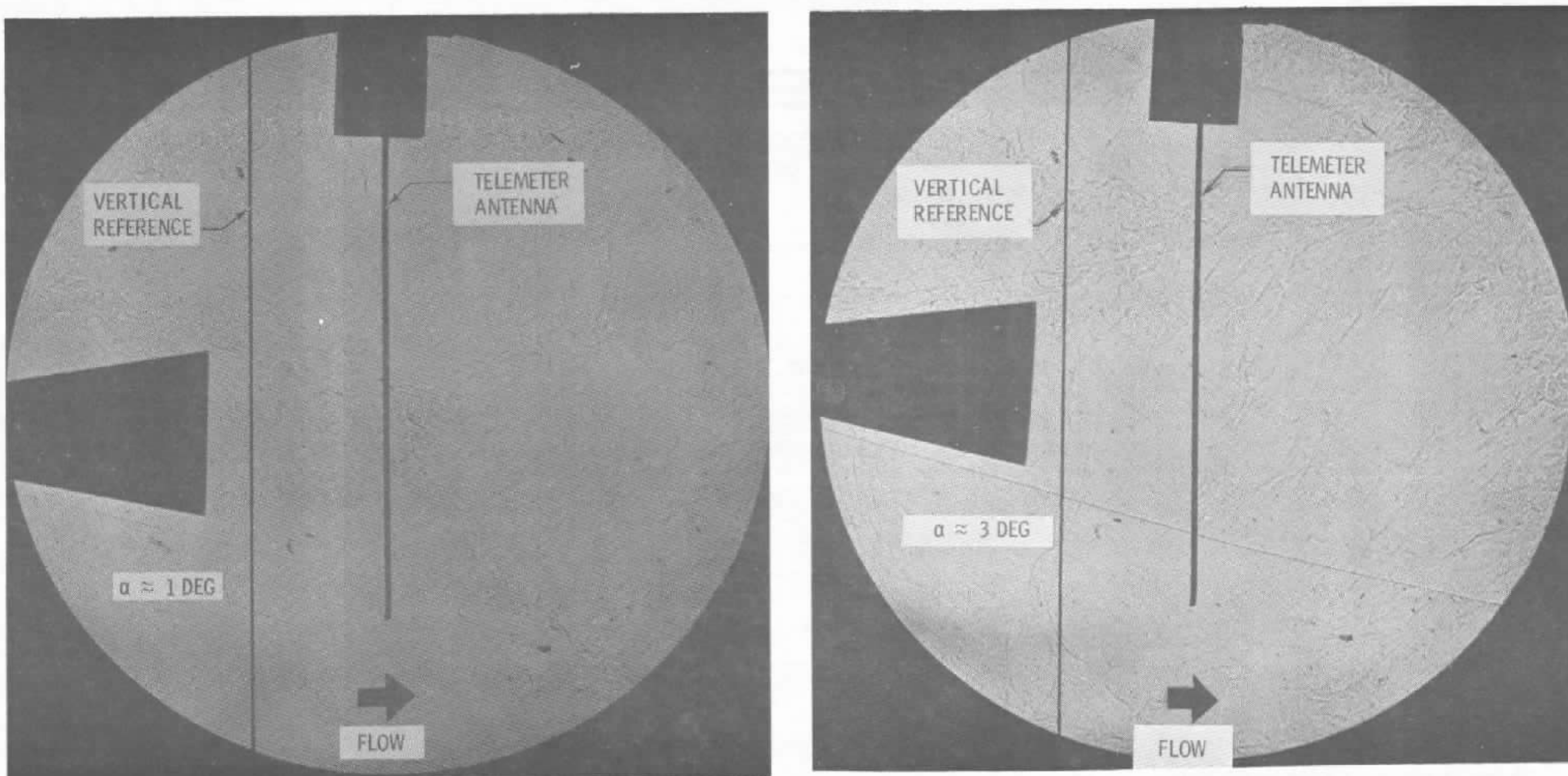


Fig. 14 Typical Oscillograph Trace Obtained during Base Pressure Tests



a. $Re_{\ell} = 1.05 \times 10^6$

b. $Re_{\ell} = 1.95 \times 10^6$

Fig. 15 Shadowgraph Pictures of 10-deg Cone in Free Flight at Mach 10

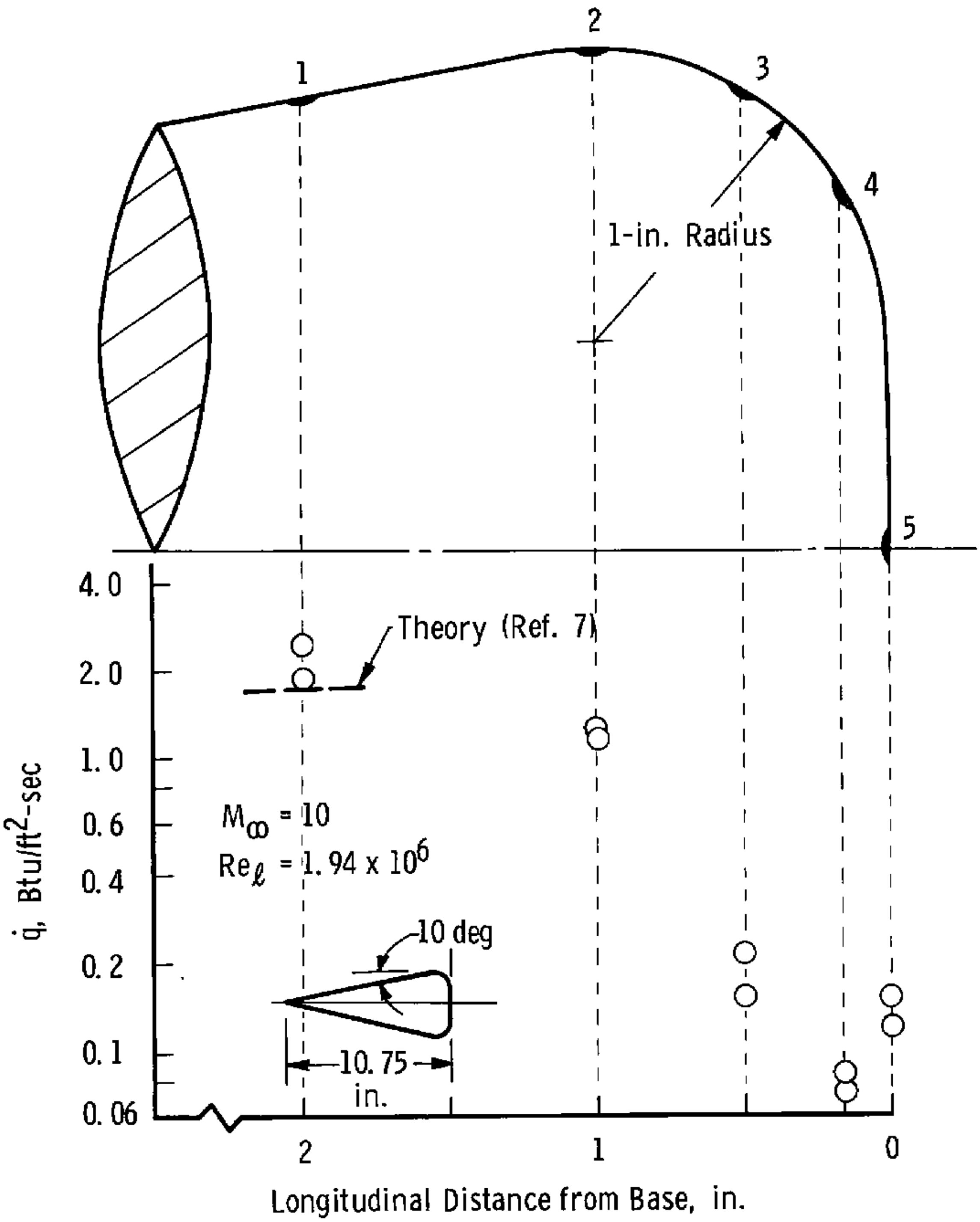


Fig. 16 Free-Flight Model Heating Rate Measurements

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13 ABSTRACT

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